FAME Space/Ground Interface - Goals

- CCSDS compliance
  - CCSDS encoding supports data integrity
  - COTS ground equipment support CCSDS
- Frame size must support low bit rates
  - during early orbits our bit rates will be as low as 1, 2, 4, 8 Kbps
  - a small frame size reduces commanding delays

Telemetry Formats

(CCSDS Grade 2 with insert, SLS multiplexing or bitstream service)

VCDU - Virtual Channel Data Unit - VC0
512 bytes - the CLCW contains AuthCnt

	VCDU PRIMARY HEADER						VCDU INSERT ZONE	M_PDU HEADER		M_PDU PACKET DATA ZONE	VCDU TRAILER	
SYNC MARK	VER #	S/C ID	VIRT. CHAN	VCDU CNTR	RE-PLAY FLAG	SPARE	Clock Counts	SPARE	1ST HDR POINTER	PACKET DATA	CLCW	REED SOLOMON CHECK SYMBOLS
32	2	8	6	24	1	7	32	5	11	3424=428*8	32	512=64*8

VCDU - For non-housekeeping data - VCn
512 bytes

	VCDU PRIMARY HEADER						VCDU INSERT ZONE	M_PDU HEADER		M_PDU PACKET DATA ZONE	
SYNC MARK	VER #	S/C ID	VIRT. CHAN	VCDU CNTR	RE-PLAY FLAG	SPARE	Clock Counts	SPARE	1ST HDR POINTER	PACKET DATA	REED SOLOMON CHECK SYMBOLS
32	2	8	6	24	1	7	32	5	11	3456=432*8	512=64*8

Note: the normal CRC field is not needed with the Reed-Solomon symbols.
Note the maximum application packet is 428 bytes

VCDU Details

Field Name	Size in Bits	Description/Value
Sync Marker	32	Sync Pattern = 0x1ACFFC1D
VCDU Primary Header: -Version Number	2	(Bits= “01”): identifies the CCSDS Virtual Channel Data Unit.
VCDU Primary Header: -Spacecraft Identifier	8	0x039 (TBR)
VCDU Primary Header: -Virtual Channel Identifier	6	Major sorting field. 0=House Keeping, 1=payload, 2=start tracker, etc.
VCDU Primary Header: -VCDU Counter	24	Keeps a modulo 16,777,216 count for each VCID. The VCDU field allows ground processing to detect loss of synchronization within a given virtual channel in the downlink.
VCDU Primary Header: -Replay Flag	1	0=Realtime data 1=playback data (i.e., from a SSR or stored in RAM)
VCDU Primary Header: -Spare	6	Set to zero.
VCDU Insert Zone: -Clock Counts	32	FAME clock ticks during VCDU Frame release. This value should be filled as close to VCDU downlink as possible.
M_PDU Header: -Spare	5	Set to zero.
M_PDU Header: -First Header Pointer	11	Byte offset into the M_DPU data area of the first complete M_PDU packet in this frame. This allows the ground to deal with M_PDUs that span VCDU frames. For example, a value of zero indicates that there is no “left over” portion of a M_PDU in this frame. A value of 100 means that bytes 0 –99 of the M_PDU data area are from a previous message and the first full M_PDU message in this frame starts at byte offset 100 of the M_PDU data area. If no M_PDU headers are contained with in the transfer frame, set the value to 11111111111. If the transfer frame contains only idle data, set the value to 11111111110. (see CCSDS 701.0-B-2)
M_PDU Packet Zone	3324 or 3456	This area holds the M_PDU packets. The size of this zone will be 3504 bits for VC0 (the housekeeping telemetry). The VC0 contains the CLCW field below. The other VCIDs do not have this field and therefore the M_PDU packet zone is 4 bytes larger (3536 bits total).
VCDU Trailer: -Command Link Control Word (CLCW)—VC0 only	32	The CLCW field allows the satellite and ground to validate commanding.
Reed-Solomon Check Symbols	160*8	The Reed-Solomon code is defined in CCSDS 101.0-B-3: Telemetry Channel Coding. Issue 3. May 1992. To insure 32-bit compatibility, the technique of virtual fill is used. For FAME, I=2 (Interleave Depth) and n=2 (Virtual Fill). The Reed-Solomon Code is calculated on the VCDU only and not the Sync Pattern.

Command Link Control Word (CLCW) Format

Control Word Type	CLCW Ver. #	Status	COP	VCID	Spare	RF Avail	No Bit Lock	Lock Out	Wait	Re-trans-mit	FARM	Spare	Report Value
(1)	(2)	(3)	(2)	(6)	(2)	(1)	(1)	(1)	(1)	(1)	(2)	(1)	(8)

CLCW Details

CLCW Subfield Name	Size in Bits	Description/Value
VCDU Trailer CLCW-Control Word Type	1	As per CCSDS, set to zero.
VCDU Trailer CLCW-CLCW Version Number.	2	As per CCSDS, set to zero.
VCDU Trailer CLCW-Status field	3	Not used. Set to zero.
VCDU Trailer CLCW-Command Operation Procedure (COP) in Effect	2	Only COP-1 is supported by FAME. Set to zero.
VCDU Trailer CLCW-VCID	6	Indicates which VCID is being reported on by this CLCW. Set to 0.
VCDU Trailer CLCW-Spare	2	Set to zero.
VCDU Trailer CLCW-RF Available	1	0=RF path is available 1=RF path is not available.
VCDU Trailer CLCW-No Bit Lock	1	0=bit lock achieved 1=no bit lock
VCDU Trailer CLCW-Lockout	1	0=no COP-1 lockout 1=COP-1 lockout
VCDU Trailer CLCW-Wait	1	Unused. Set to zero.
VCDU Trailer CLCW-Retransmit	1	This field is used as per COP-1 as per the CCSDS recommendations. 0=no need to retransmit 1=retransmit is needed.
VCDU Trailer CLCW-Frame Acceptance and Reporting Mechanisms (FARM)-B Counter	2	This field provides verification of bypass commands. It increments for each bypass command accepted.
VCDU Trailer CLCW-Spare	1	Set to zero.
VCDU Trailer CLCW-Report Value	8	This field contains the current observed value of the FARM's next expected frame sequence number. The FARM V(R) counter shall increment once each time a TC Transfer Frame is accepted. This serves as an authentication counter.

Application Telemetry Format

Packet Identification				Packet Sequence Control		Packet Length	Secondary Header	User Data Field
Version	Type	Secondary Header Flag	Application Process ID	Sequence Flags	Source Sequence Count	Packet Length	Clock Counts	Application Data
'000'	'1'	'1'=present	(0-2046 decimal) (2047 dec. = fill	'11'				
(3)	(1)	(1)	(11)	(2)	(14)	(16)	(32)	(N*8)

CCSDS Application Telemetry Packet

Application Process Id	Used to identify the message
Source Sequence Count	A modulo 16384 counter for each Application Id
Packet Length	Length of the fields to follow in bytes -1 (ex. If there is one byte of Application data, the packet length is 2.
Clock Counts	FAME specific clock ticks. The payload will use its own clock. The satellite controller will use its clock (TBR).

Note the maximum application packet is 438 bytes - this is not a CCSDS limit.
The limit for the payload status packets will be set by the 1553 schedule.

Telemetry Overhead

- VCDU overhead 84/512= 0.164
- The application packets are variable length. The overhead is fixed at 10 bytes/packet. Assume we have 4 application packets with 100 user data bytes each. The overhead in this VCDU is 84+40 /512 = 0.24 (8 bytes of the last packet will be in the next VCDU of this type)

Downlink Encoding (CCSDS)

- Reed-Solomon Interleave=2, Virtual Fill N=2
- Psuedorandomization with $h(x) = x^8+x^7+x^5+x^3+1$
- Convolutional Encoding/Viterbi Decoding

Item	Description
Nomenclature	Convolutional code with maximum-likelihood (Viterbi) decoding
Code Rate	1/2 bit per symbol
Constraint Length	7 bits
Initialization Bits	G1 = 1111001 G2 = 1011011
Phase Relationship	G1 is associated with first Symbol
Symbol Inversion	On output path of G2

Downlink Frame Rates

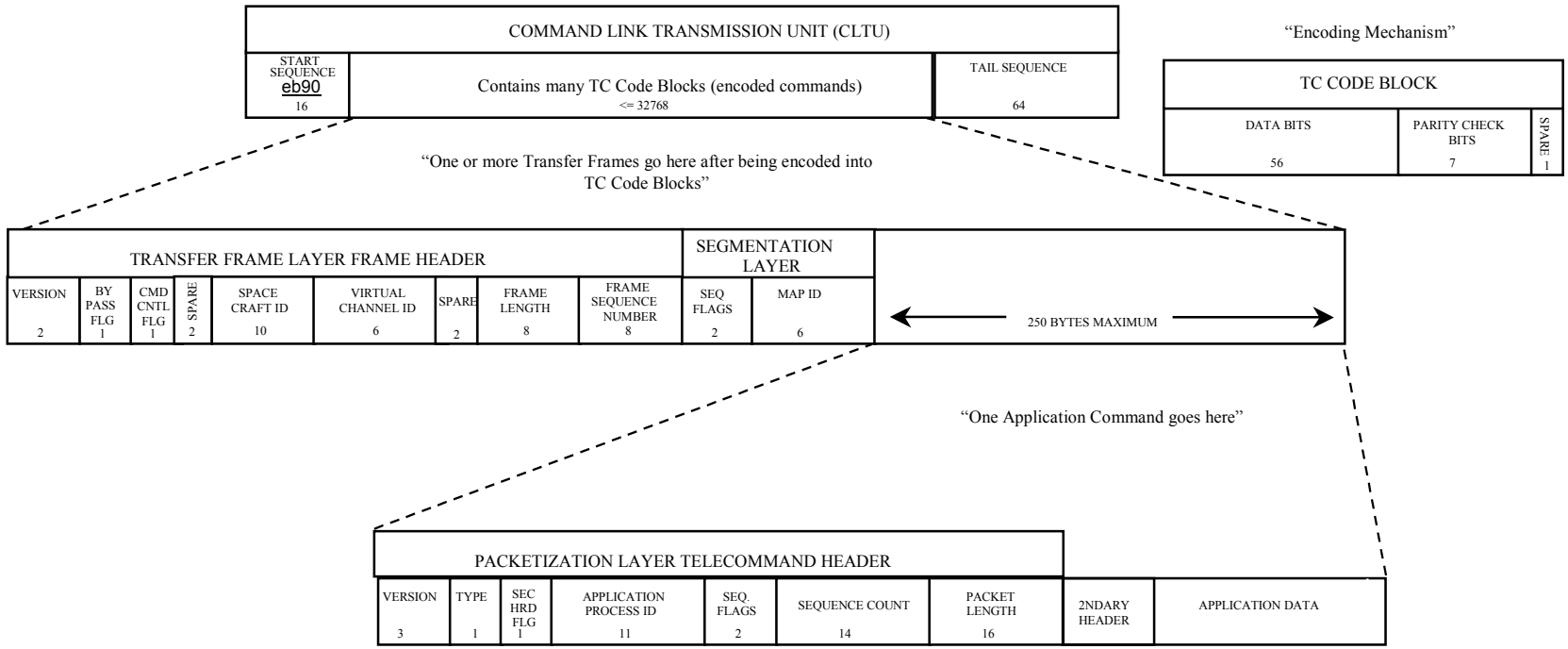
- 512 bytes per frame*8 = 4096 bits per Frame
- At 1 Kbps 4096/1000 = 4.096 secs/frame
- This may result (worst case) in 8.2 seconds before the CLCW reflects the command.

- At 409Kbps 4096/409000 => 99.8 frames/sec
  - Command verification speed will not be a problem

Sample VCID usage

- VCID=0 - Housekeeping telemetry and CLCW
- VCID=1 - Payload data
- VCID=2 - Star tracker image dump
- etc.

Command Data Layers



Note the maximum application command packet is 250 bytes - this is not a CCSDS limit.
The limit for the payload command packets will be set by the 1553 schedule.

COMMAND LINK TRANSMISSION UNIT (CLTU)

Field Name	Size in Bits	Field Description
Start Sequence	16	A sync pattern set to 0xEB90.
TC Code Blocks	<= 32512	The TeleCommand (TC) Code Blocks encode the actual command. The format of the TC Code Block is described below.
Tail Sequence	64	Set to 0xC5C5C5C5C5C5C579.

TC CODE BLOCK (CLTU)

Field Name	Size in Bits	Field Description
Command Data Bits	56	Seven bytes of command data. The parity bit for each byte is contained below. [If a TC code block contains less than 7 bytes of 'real' data, fill shall be inserted]
7 Parity Bits	7	Seven odd parity bits for the seven bytes above. The code used is a (63,56) modified Bose-Chaudhuri-Hocquenghem (BCH) code which uses the following generator polynomial to produce the seven parity bits: $g(x) = x^7+x^6+x^2+1$ (See CCSDS 201.0-B-2 Figure 3-4 for details.)
Spare Bits	1	Set to zero.

TRANSFER FRAME - Details

Field Name	Size in Bits	Field Description
Transfer Frame Layer Frame Header: -Version Number	2	The value will be zero.
Transfer Frame Layer Frame Header: -Bypass Flag	1	0—Use normal COP-1 frame validation 1—Bypass the COP-1 frame validation.
Transfer Frame Layer Frame Header: -COP-1 Control Command flag	1	0—Normal Command 1—The Control Command flag is set to 1 to support two commands: one to reset the Frame Sequence Number to zero and one to unlock the commanding system after a COP-1 lockout.
Transfer Frame Layer Frame Header: -Spare	2	Set to zero.
Transfer Frame Layer Frame Header: -Satellite Identifier	10	Set to 0x039 for FSC decoder side A Set to 0x040 for FSC decoder side B
Transfer Frame Layer Frame Header: -Virtual Channel Identifier	6	Set to 000001 for these normal commands. (Recall that this field is set to 000010 for the special commands.)
Transfer Frame Layer Frame Header: -Spare	2	Set to zero.
Transfer Frame Layer Frame Header: -Frame Length	8	The zero relative byte count of the transfer frame. The minimum value is 13 (6 bytes of transfer frame header, 1 byte for the segmentation layer and 7 bytes for an application command).
Transfer Frame Layer Frame Header: -Frame Sequence Number	8	A counter of the number of frames sent by the commanding system. This allows the satellite to detect a loss of frame(s).
Segmentation Layer: -Sequence Flags	2	A bit counter of packets. (set to 11) 11—This is the only segment 00—This is the first segment of a sequence 01—This is a continuation of a sequence 10—This is the last segment of a sequence
Segmentation Layer: -Multiplexer Access Point (Map) Identifier	6	Set to zero. This field allows the multiplexing of commands for a given Virtual Channel Identifier. Not used on NEMO.

Application Command Fields - Details

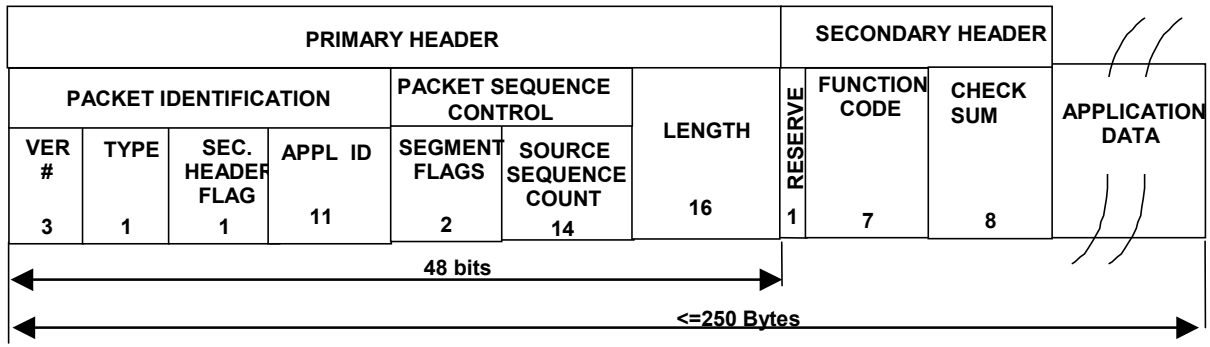
Field Name	Size in Bits	Field Description
--Version Number	3	The value will be zero.
--Type	1	0—Telemetry Packet 1—Command Packet The value is set to one.
--Secondary Header Flag	1	0—No secondary header is present 1—Secondary header is present. All command packets shall include a secondary header as defined below.
--Application Process Identifier	11	This is the primary method for identifying packets. The application identification assignments shall be in the NEMO Data Formats documents.
-Packet Sequence Control: --Segment Flags	2	11—Standalone packet 00—First Packet of a sequence 01—Continuation packet 10—Last packet of a sequence. Unsegmented packets shall set the bits to '11' meaning the packet is the first and last segment. NEMO will use unsegmented only.
-Packet Sequence Control: --Source Sequence Count	14	Not used by FAME - Set to 0
-Packet Length	16	A zero relative byte count of the secondary header and application data fields. Maximum value - 183.
Secondary Header: -Reserved	1	Set to zero.
Secondary Header: -Function Code	7	Used in combination with the application identification to identify the command.
Secondary Header: -Checksum		Used for an exclusive-OR bit wise checksum. The "odd parity" checksum is computed over the complete packet (with the 8-bit checksum field being initialized to 0). For example, if the exclusive-OR of the bytes (from the Primary Header through the Application data is 0xCC, the checksum field is set to 0x33. The NSC validates the packet by ensuring that the bit wise exclusive-OR of the bytes results in 0xFF
Application Data	<=1456	Data to support the command. To ensure bit transition density, this field will be randomized by exclusive-OR'ing the field with a fixed pattern of 0xA55A. This randomization occurs after the generation of the checksum in the secondary header.

Commanding Verification

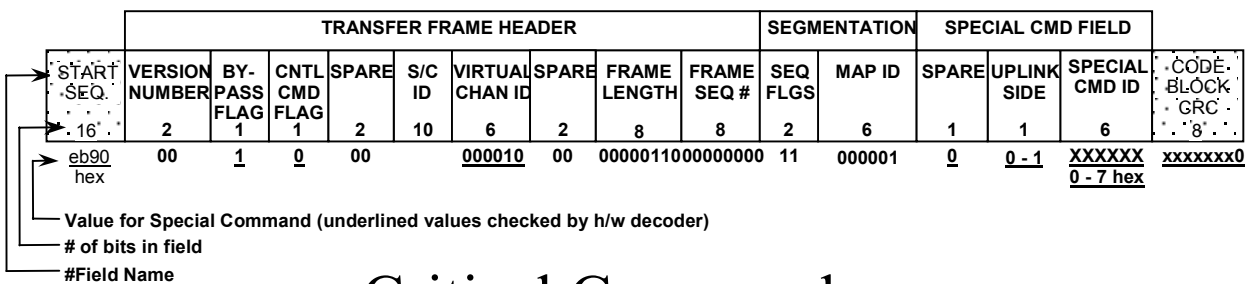
Field	Verification Method
Sync Word	Match
Code block Parity Bits	Match
Satellite Identifier	Match
Version Number	Match
Frame length	Match
Sequence Number	COP-1 Match with a ±63 Sliding Window*
Packet Checksum	Match
Application Identifier	Valid (i.e., in the ICD)

* If the sequence number is outside of a ± 63 count window, FAME will declare that unauthorized commanding has been attempted. The lockout bit will be set in the CLCW.

Command Data Formats



Packetized Commands



Critical Commands

Critical Command Fields - Details

Field Name	Size in Bits	Field Desciption
Start Sequence	16	A sync pattern set to 0xEB90.
-Version Number	2	Set to 00.
-Bypass Flag	1	Set to 1 (bypass frame validation).
-Control Command Flag	1	Set to 0.
-Spare	2	Set to 00.
-Satellite Identifier	10	Set to 0x039 for FAME side A Set to 0x040 for FAME side B
-Virtual Channel	6	Set to 000010.
-Spare	2	Set to 00.
-Frame Length	8	A zero relative byte count of the message size. Set to 00000110.
-Sequence Number	8	Set to 00000000.
-Sequence Flags	2	Set to 11 (this is the only segment).
-MAP Identifier	6	Set to 000001.
High Priority Command Field: -Spare	1	Set to 0.
High Priority Command Field: -Uplink Side	1	0=Primary command receiver 1=Redundant command receiver.
High Priority Command Field: -Special Command Identifier	6	This field identifies the command to execute.
Parity Check Bits: -7 Parity Bits	7	Seven odd parity bits for the seven bytes above. The code used is a (63,56) modified Bose-Chaudhuri-Hocquenghem (BCH) code which uses the following generator polynomial to produce the seven parity bits: $g(x)=x^7+x^6+x^2+1$ (See CCSDS 201.0-B-2 Figure 3-1 for details).
Parity Check Bits: -Spare Bit	1	Set to zero.
Tail Sequence	64	Set to 0XC5C5C5C5C5C5C579